Navigation R&D
Coastal Structures
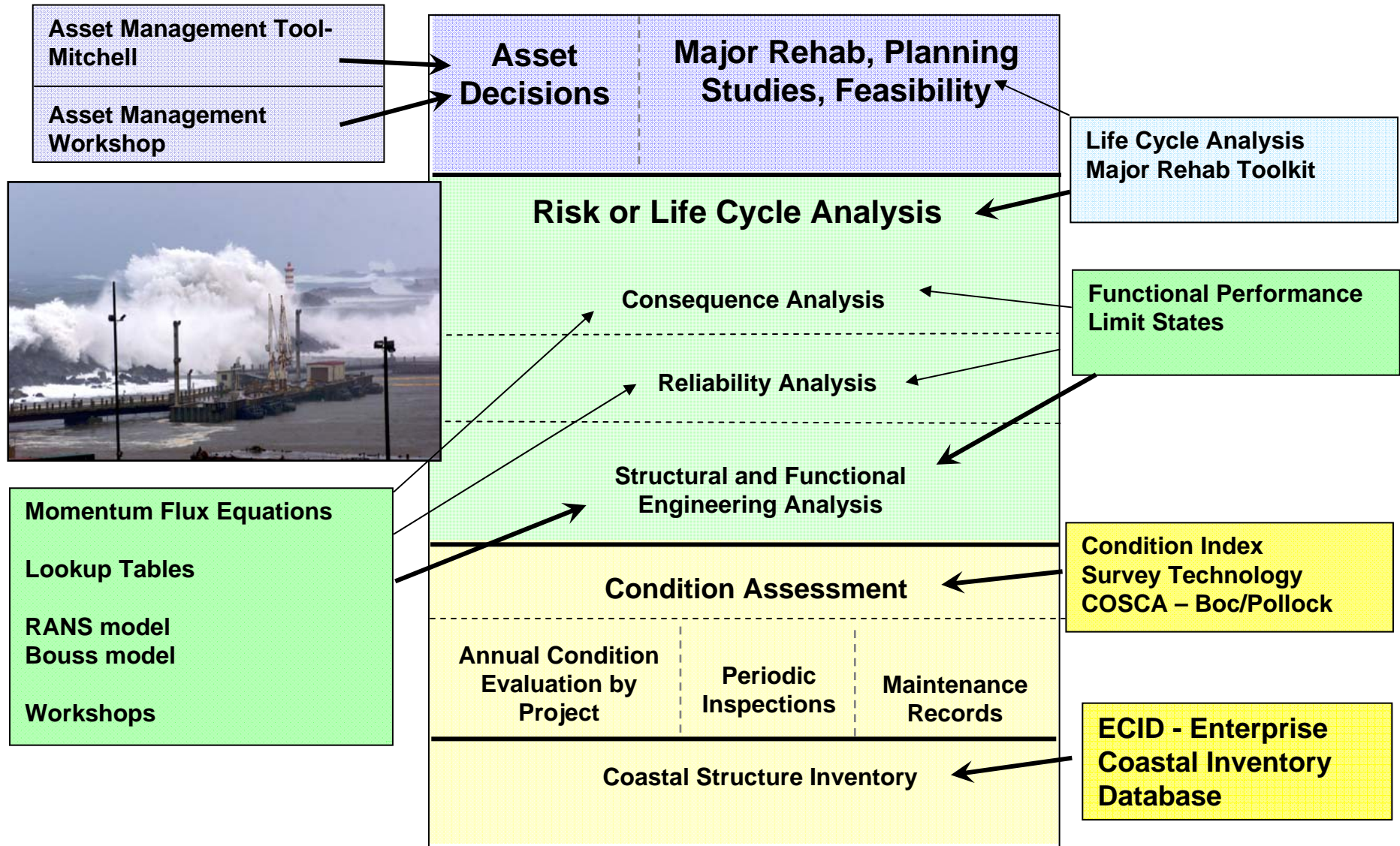
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THE DAY AFTER TOMORROW

Coastal Structure R&D

Asset Management Tool-Mitchell

Asset Management Workshop

Asset Decisions

Major Rehab, Planning Studies, Feasibility

Life Cycle Analysis Major Rehab Toolkit

Risk or Life Cycle Analysis

Consequence Analysis

Functional Performance Limit States

Reliability Analysis

Structural and Functional Engineering Analysis

Momentum Flux Equations

Lookup Tables

RANS model Bouss model

Workshops

Condition Assessment

Condition Index Survey Technology COSCA – Boc/Pollock

Annual Condition Evaluation by Project	Periodic Inspections	Maintenance Records

Coastal Structure Inventory

ECID - Enterprise Coastal Inventory Database

Enterprise Coastal Inventory

http://chl.erdc.usace.army.mil/chl.aspx?p=s&a=Projects;246

https://corpsglobeweb.usace.army.mil/ECID/ECID.kml

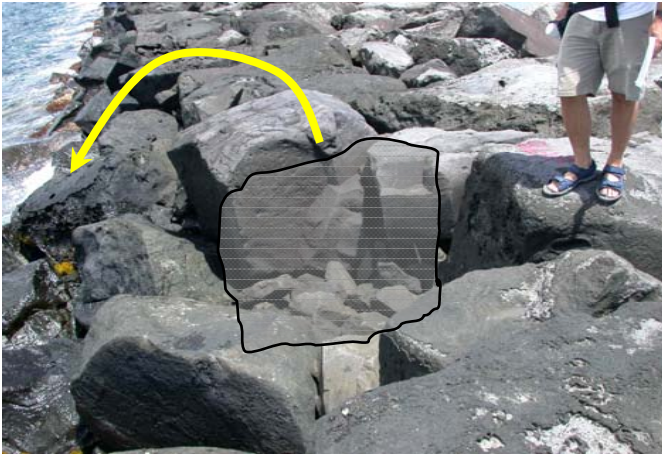https://corpsglobeweb.usace.army.mil/ecid

Elizabeth Burg, CHL

James Stinson, ITL

Engineering Analysis

Physics-Based Empirical Equations

Armor Stability, Seaside Damage, Leeside Damage, Jetty and Breakwater Damage
e.g. Melby and Hughes (CS 2003), CHETN III-71
Maximum force proportional to Maximum Wave Momentum Flux per unit crest length

Wave Momentum Flux

$$\frac{(M_F)_{max}}{\rho_w g h^2} = \frac{1}{2}\frac{H}{h}\frac{\tanh kh}{kh} + \frac{1}{8}\left(\frac{H}{h}\right)^2\left[1 + \frac{2kh}{\sinh 2kh}\right]$$

Stability Number

$$N_m = \left(\frac{K_a(M_F)_{max}}{(S_r - 1)\rho_w g h^2}\right)^{1/2}\frac{h}{D_n}$$

Plunging Waves

$$N_m = 5.0(S/N_z^{0.5})^{0.2}P^{0.18}\sqrt{\cot\alpha} \qquad s_m \geq s_{mc}$$

Surging Waves

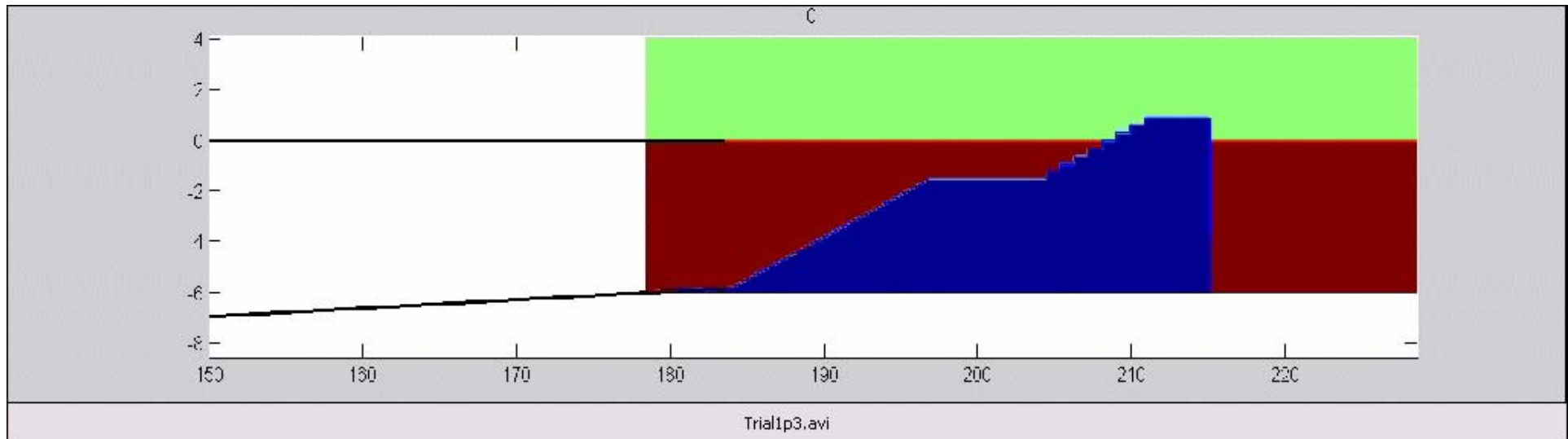$$N_m = 5.0(S/N_z^{0.5})^{0.2}P^{0.18}(\cot\alpha)^{0.5-P}s_m^{-P/3} \qquad s_m < s_{mc}$$
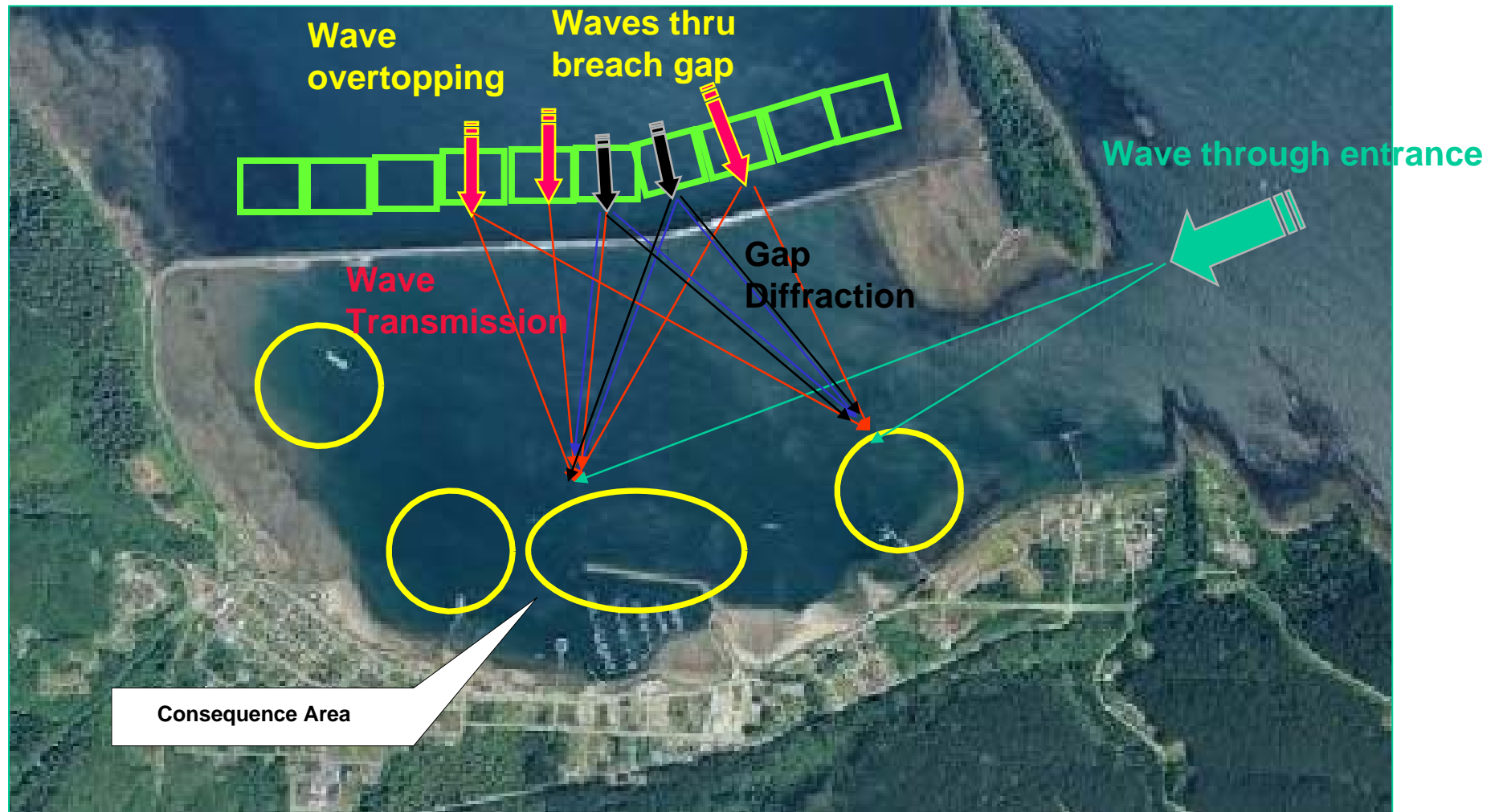
$$s_{mc} = -0.0035\cot\alpha + 0.03316$$

RANS Model
SAJ Reservoir Embankment

Optimize cross-section geometry and slab thickness
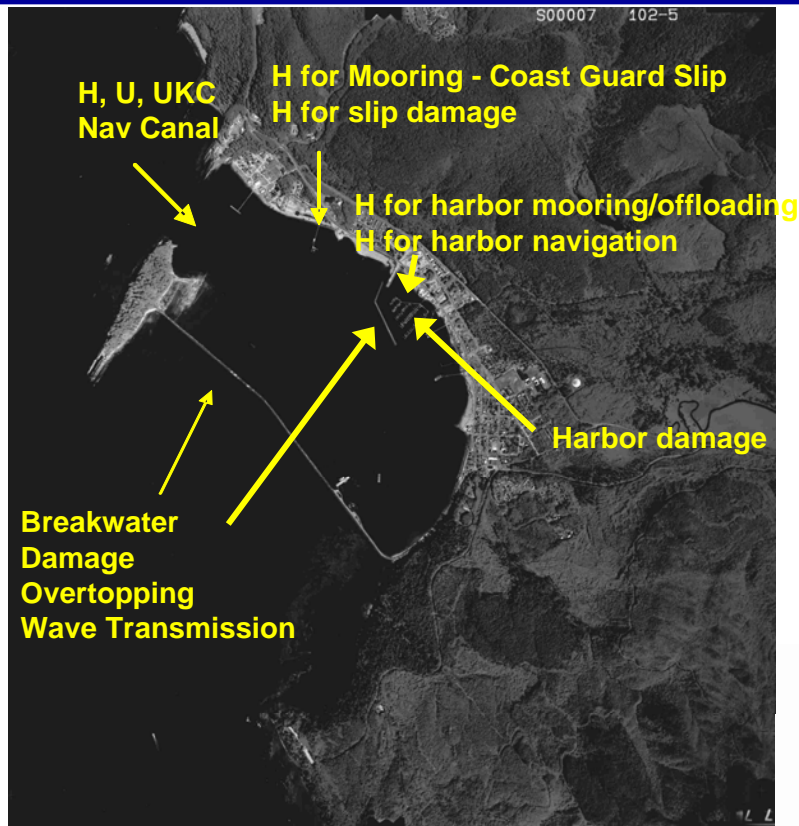
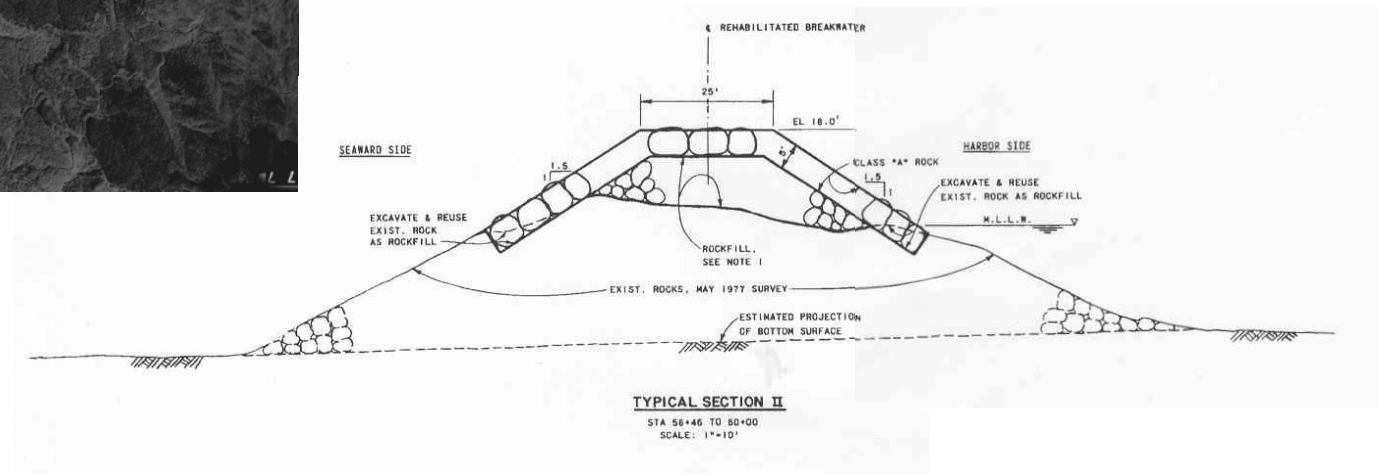# Life-Cycle Simulation

RMDamRisk → Major Rehab Toolkit

- Historical wave and water level time history at structure
- Compute extremal distributions
- Design structure cross sections for select return periods
    - Crest height, slopes, armor stone, toe stone, toe berm, compound slope, low crest…
- Simulate likely future wave and water level time histories
    - WELS, JP, EST, Monte Carlo – 10,000 life-cycles
- For each return period cross-section, compute life-cycle damage, transmission, repair costs and consequence costs
- User input: Repair rules, fixed costs, material costs
- Compute PUPs for structural/functional limit states
- Compute total present worth and annualized costs
- Pick least cost alternative given damage criterion

Life Cycle Simulation

H, U, UKC
Nav Canal

H for Mooring - Coast Guard Slip
H for slip damage

H for harbor mooring/offloading
H for harbor navigation

Harbor damage

Breakwater
Damage
Overtopping
Wave Transmission

Technical Report

Summary of Primary Limit States

Lookup Table Tool

- Generate lookup tables with Boussinesq and RANS models
  - Wave runup and overtopping
  - Wave diffraction
  - Levee erosion

- To use lookup tables, enter nearshore bathym., structure, harbor geometry, wave and water level - tool interpolates solution
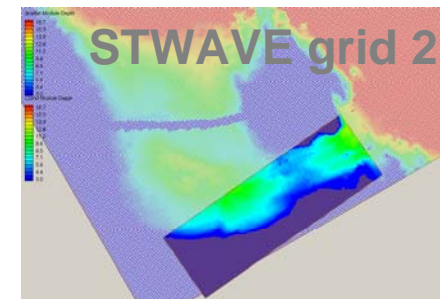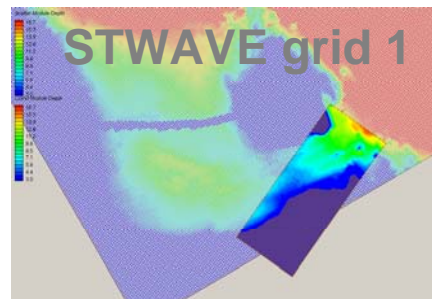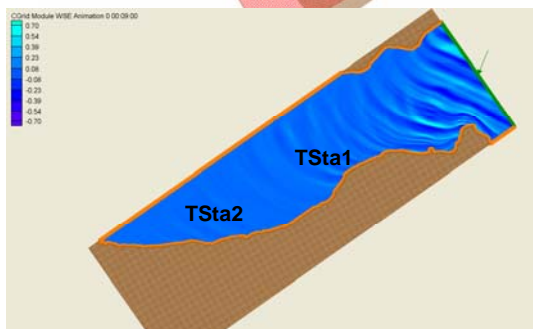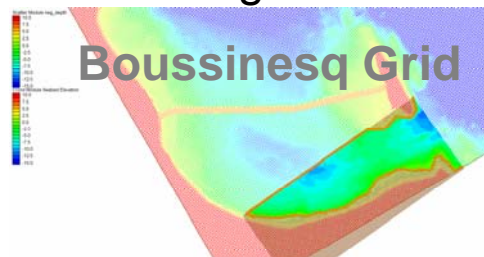
Functional Assessment - Wave Transmission

- Generated lookup table of transmission coefficients for each save locations n (e.g. small boat harbor, coast guard slip)

- Wave transmission over breakwater $\longrightarrow$ $\left(H_{t,BW}^2\right)_n = \sum_{m=1}^{10} \left(H_{i,BW}\sqrt{(C_{t,breach}^2)_n + C_{t,OT}^2}\right)_m^2$

  - Intact sections and breached sections

  - Produced general gap diffraction table

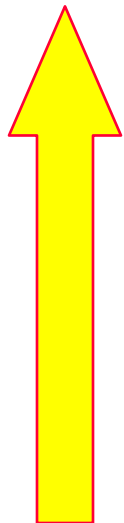- Waves through inlet $\longrightarrow$ $\left(H_{t,inlet}^2\right)_n = \left(H_{i,inlet}(C_{t,inlet})_n\right)^2$

Boussinesq Grid

TSta1

TSta2

STWAVE grid 1

STWAVE grid 2

Total Transmission: $(H_t)_n = \left(\sqrt{H_{t,inlet}^2 + H_{t,BW}^2}\right)_n$

Consequences * PUP = Risk

PUP = Probability of Unsatisfactory Performance
**Annual probabilities computed from
an engineering reliability model**

Cost Examples
Emergency Repairs
Delay/Down Times for Users
Increased O & M Costs and/or Frequency
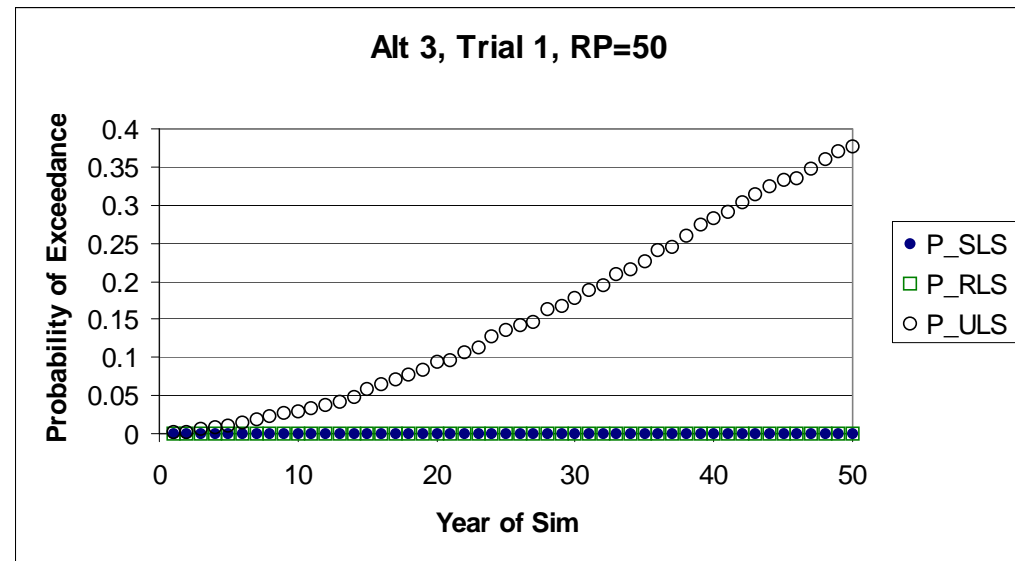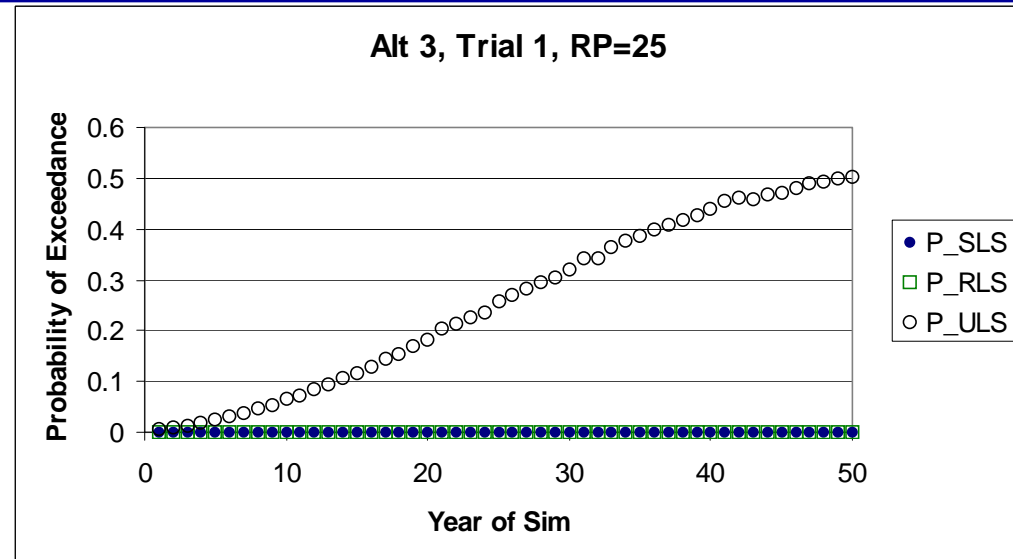**Damages to Infrastructure**
Benefits Foregone

Event Tree

Probability of Exceeding Breakwater Damage Limit States

Alt 3, Trial 1, RP=25

Alt 3, Trial 1, RP=50

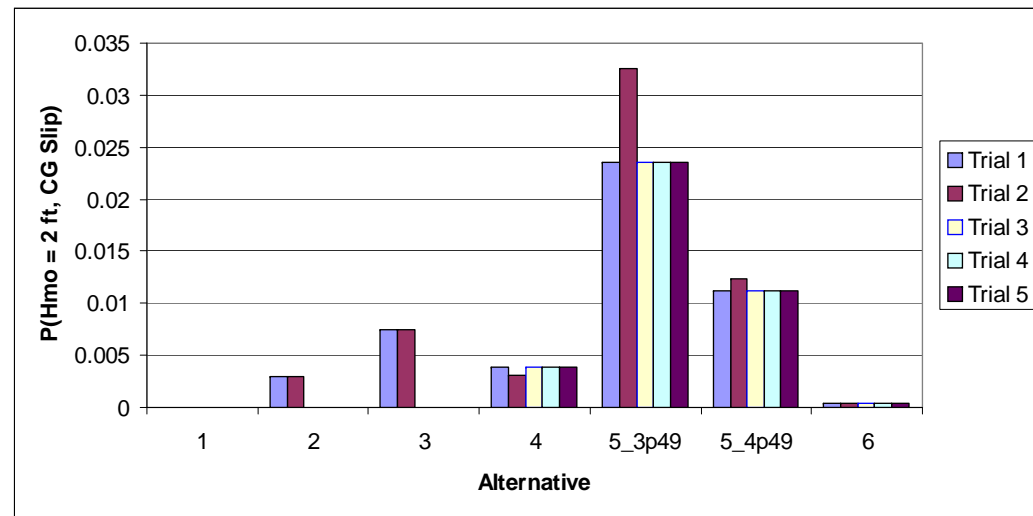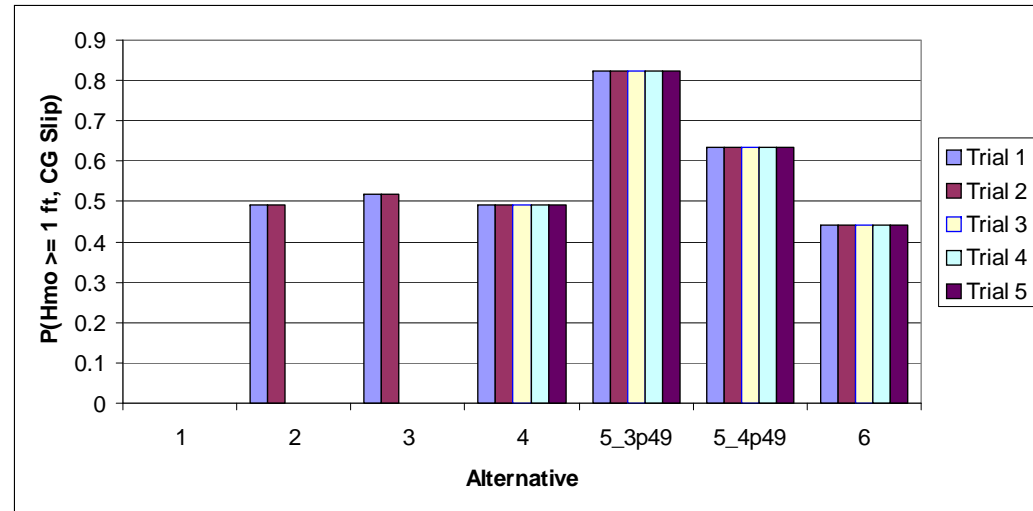## Probability of Exceeding Wave Transmission Limit States

U.S. Coast Guard Slip Return period of 50 years: $W_{50} = 7$ tons

Total Present Worth Cost

Compute costs in todays dollars

First Cost   Repairs   Consequences

$$C_T = C_F \left(\frac{1}{1+p} \right)^{lag} + \sum_{m=lag}^{N+lag} \left[\sum_{x=1}^{X} P_{Rx}(t)C_{Rx} + \sum_{y=1}^{Y} K_B P_{Cy}(t)C_{Cy} \right] \left(\frac{1}{1+p} \right)^{m}$$

Sum different limit states and various repair classes

C_F = initial construction costs

m = specific year in life cycle

Lag = time from analysis until initial construction

p = discount rate

P_{Rx} = exceedance probability for damage limit state x

C_{Rx} = repair cost for damage limit state x

P_{Cy} = exceedance probability for transmission limit state y

C_{Cy} = consequence cost for transmission limit state y

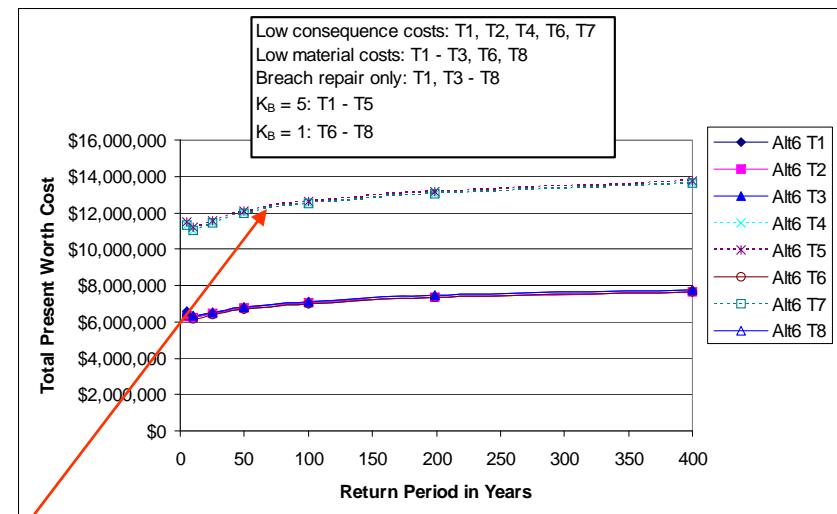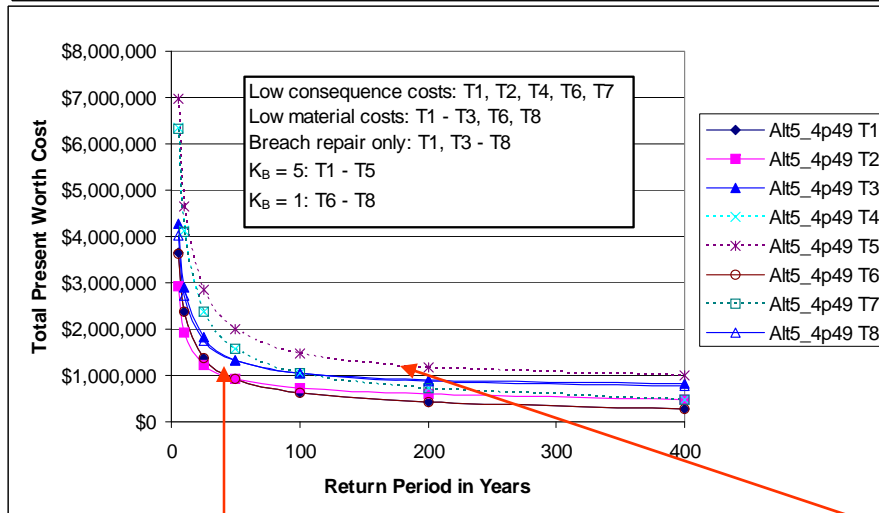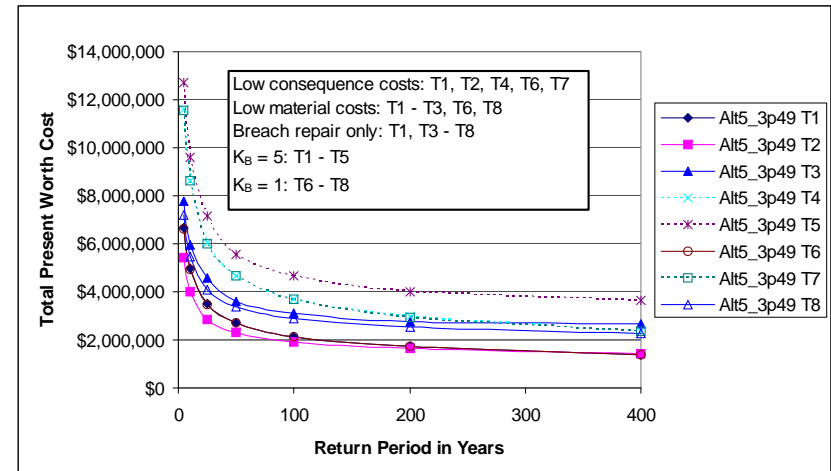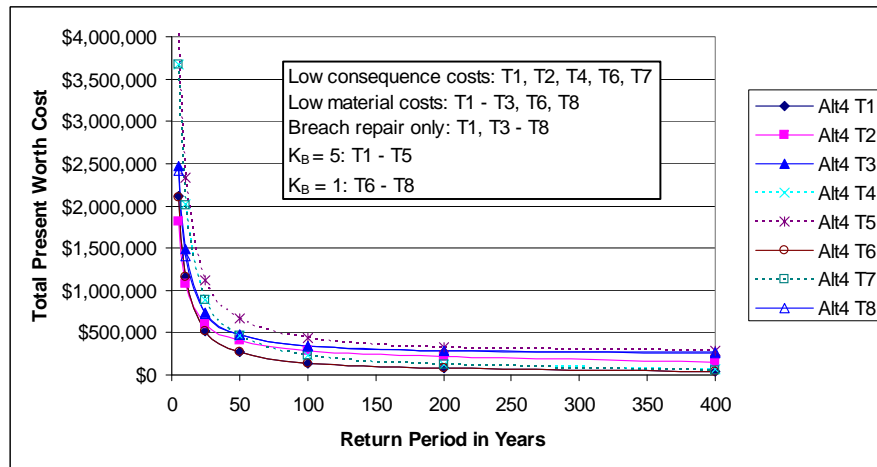K_B = breach cost factor to take into additional consequence costs when sections are breached

N = number of years in economic life

Total Costs

Top-left chart:
- Low consequence costs: T1, T2, T4, T6, T7
- Low material costs: T1 - T3, T6, T8
- Breach repair only: T1, T3 - T8
- $K_B = 5$: T1 - T5
- $K_B = 1$: T6 - T8

Legend: Alt4 T1, Alt4 T2, Alt4 T3, Alt4 T4, Alt4 T5, Alt4 T6, Alt4 T7, Alt4 T8

Top-right chart:
- Low consequence costs: T1, T2, T4, T6, T7
- Low material costs: T1 - T3, T6, T8
- Breach repair only: T1, T3 - T8
- $K_B = 5$: T1 - T5
- $K_B = 1$: T6 - T8

Legend: Alt5_3p49 T1, Alt5_3p49 T2, Alt5_3p49 T3, Alt5_3p49 T4, Alt5_3p49 T5, Alt5_3p49 T6, Alt5_3p49 T7, Alt5_3p49 T8

Bottom-left chart:
- Low consequence costs: T1, T2, T4, T6, T7
- Low material costs: T1 - T3, T6, T8
- Breach repair only: T1, T3 - T8
- $K_B = 5$: T1 - T5
- $K_B = 1$: T6 - T8

Legend: Alt5_4p49 T1, Alt5_4p49 T2, Alt5_4p49 T3, Alt5_4p49 T4, Alt5_4p49 T5, Alt5_4p49 T6, Alt5_4p49 T7, Alt5_4p49 T8

Bottom-right chart:
- Low consequence costs: T1, T2, T4, T6, T7
- Low material costs: T1 - T3, T6, T8
- Breach repair only: T1, T3 - T8
- $K_B = 5$: T1 - T5
- $K_B = 1$: T6 - T8

Legend: Alt6 T1, Alt6 T2, Alt6 T3, Alt6 T4, Alt6 T5, Alt6 T6, Alt6 T7, Alt6 T8

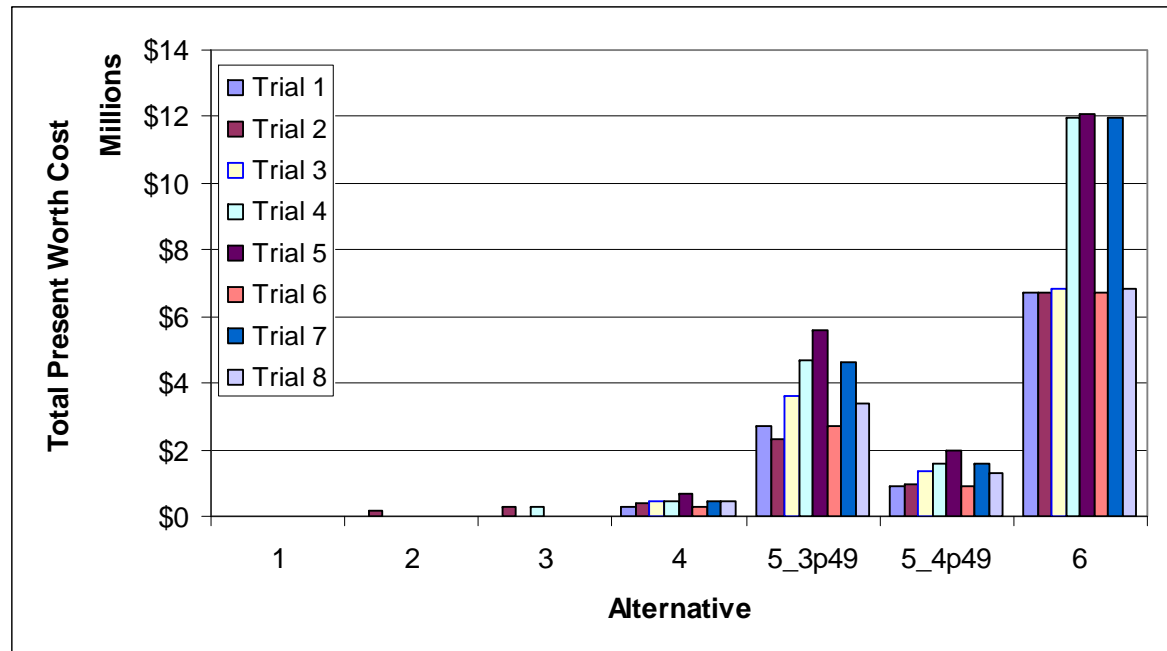**High consequence costs**

High material costs

Alternative 4 is least total cost –
No rehab, repair breaches

Conclusions

- Risk increasing
  - Increased vulnerability because built environmenrt is more dense
  - Increased probability of severe damage with deteriorated structure/deferred maintenance
  - Increased storm frequency/intensity and SLR

- Models not that good and some don't exist (e.g. ice, stone breakage, laid up stone damage, trestle dumped stone stability)

- Cause and effect may not be clear

- Many projects have not had any rigorous engineering analysis, let alone a risk study

- Need risk to be defined relative to standard engineering practice

- Do we need a national PRA for coastal structures?